Surgical treatment of intact thoracoabdominal aortic aneurysms in the United States: Hospital and surgeon volume-related outcomes

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Objective: **Surgical treatment of intact thoracoabdominal aortic aneurysm (TAAA) is crucial to prevent rupture but is associated with high perioperative mortality. We tested the hypothesis that provider volume of surgical treatment of TAAA is an important determinant of operative outcome.**

Patients and methods: **Clinical information regarding repair of intact TAAA in 1542 patients from 1988 to 1998 was obtained from the Nationwide Inpatient Sample (NIS), a stratified discharge database of a representative 20% of US hospitals. Demographic data included age, sex, race, nature of admission, and comorbid conditions. Annual hospital volume of TAAA treated was grouped into terciles and defined as low (LVH; 1-3 cases [median, 1]), medium (MVH; 2-9 cases [median, 4]), or high (HVH; 5-31 cases [median, 12]). Annual surgeon volume was defined as low (LVS; 1-2 cases [median, 1]) or high (HVS; 3-18 cases [median, 7]). The primary outcome measure was in-hospital postoperative mortality. Secondary outcome measures included length of stay, and cardiac, pulmonary, and renal complications. Adjusted and unadjusted analyses were conducted.**

Results: **Overall mortality was 22.3%. Mortality improved over time. LVH and HVH differed in mortality rates (27.4% vs 15.0%; $P < .001$). Mortality between LVS and HVS also differed significantly (25.6% vs 11.0%; $P < .001$). When controlling for patient demographic data, comorbid conditions, and postoperative complications, both hospital and surgeon volume were significant predictors of mortality for intact TAAA repair (LVS: odds ratio [OR] 2.6, $P < .001$; LVH: OR 2.2, $P < .001$; and MVH: OR 1.7, $P = .004$).**

Conclusions: **Greater hospital and surgeon TAAA treatment volumes contribute to better outcome. Given the relative high perioperative mortality associated with TAAA repair, regionalization of care to high-volume providers with consistently lower postoperative mortality deserves consideration by patients, physicians, and health care planners. (J Vasc Surg 2003;37:1169-74.)**

Thoracoabdominal aortic aneurysm (TAAA) is rare but potentially lethal. Prospectively gathered natural history data for patients with untreated TAAA suggest an overall rate of rupture of 26%, with increasing age, presence of pain, chronic obstructive pulmonary disease, and large aneurysm diameter increasing the risk for rupture.[1] Perioperative mortality after repair of intact TAAA at large institutions ranges from 4% to 16%,[2-8] and overall national data suggest a mortality rate approaching 20%.[9] Furthermore, postoperative complications are often severe and include acute renal failure, paraplegia, myocardial ischemia, myocardial infarction, and prolonged ventilation.

Provider caseload volume has a significant effect on the variation in postoperative mortality and complications.[10,11] As a result, policies of regionalization have been explored for such procedures as coronary artery bypass grafting, carotid endarterectomy, esophagectomy, and abdominal aortic aneurysm (AAA) repair.[12] Although TAAA repair is much less common than other procedures considered for regionalization, the benefits of selective referral to high-volume providers may be significant because of the high procedure-related morbidity and mortality.

The objective of the present study was to test the hypothesis that provider volume of surgical treatment of TAAA in a nationally representative sample is an important determinant of outcome.

METHODS

Data source. Clinical data were derived from the Nationwide Inpatient Sample (NIS) for 1988 to 1998.[13] The NIS is a 20% random sample of US hospitals stratified by geographic region, teaching status, hospital size, and other characteristics. Participating hospitals provide 100% of their discharge abstracts for a particular calendar year. The database is maintained by the Agency for Health Care Research and Quality as part of the Healthcare Cost and Utilization Project.

TAAA repair was coded according to the International classification of diseases, ninth revision, Clinical modification (ICD-9-CM), and included ICD-9-CM 384.4, resection and replacement of the abdominal aorta, and ICD-9-CM 384.5, resection and replacement of the thoracic

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Table I. Characteristics of US hospitals with varying TAAA repair volume

	Annual hospital TAAA repair volume (median number of operations)				
	Total	*Low (1)*	*Medium (4)*	*High (12)*	P*
Hospitals (n)	308	231	61	16	—
Teaching hospital (%)	50.0	43.7	67.2	75.0	<.001
Hospital size per no. of beds (%)					
Small	6.9	7.4	6.7	0	
Medium	23.2	27.7	10.0	6.7	
Large	69.9	64.9	83.3	93.3	.012
Geographic region (%)					
Northeast	20.1	18.2	28.3	16.7	
Midwest	23.7	24.9	20.7	16.7	
South	32.1	32.0	30.2	41.6	
West	24.1	24.9	20.8	25.0	.774

TAAA, Thoracoabdominal aortic aneurysm.
*Pearson χ^2 test.

aorta.[9,14] These codes yielded a total of 2185 TAAAs. Then 1542 intact TAAAs were identified, with one of the following ICD-9-CM codes: 441.0, aortic aneurysm; 441.2, thoracic aortic aneurysm; 441.4, AAA; 441.7, TAAA without rupture; or 441.9, aortic aneurysm, not otherwise specified. TAAAs were excluded from the study if the diagnosis indicated aortic dissection (ICD-9-CM codes 441.00-441.03, dissecting thoracic or abdominal aneurysm) or rupture (ICD-9-CM codes 441.1, ruptured thoracic aneurysm; 441.3, ruptured AAA; 441.5, ruptured AAA, not otherwise specified; or 441.6, ruptured TAAA).

Data regarding age, gender, race, nature of admission, comorbid conditions, unique hospital identifier, unique surgeon identifier, vital status at discharge, length of stay (LOS), and postoperative complications were obtained directly from the database. Patient age was defined as less than 65 years or as 65 years or older. Race was categorized as white or nonwhite. Urgent and emergent admission were combined and defined as emergent; all other admission types were considered elective. Comorbid conditions were determined with the Romano modification of the Charlson comorbidity index.[15,16] Total burden of comorbid disease was represented as the sum of all comorbid conditions and reported as comorbidity score (0, 1, 2, ≥3).

Volume variables. Among TAAA repairs studied, 100% had a unique hospital identifier and 55.7% had a unique surgeon identifier (some hospitals do not permit release of any type of surgeon identifier). With these variables, total annual TAAA experience could be determined. Hospital volume was considered low (LVH), medium (MVH), or high (HVH) on the basis of volume terciles. Surgeon volume was considered low (LVS) or high (HVS) on the basis of the 50th percentile for annual volume. These determinations were made for each calendar year, to control for influence of time when investigating the effect of provider volume on outcome. Annual TAAA repair volume was 1 to 3 (median, 1) for LVH, 2 to 9 (median, 4) for MVH, and 5 to 31 (median, 12) for HVH. Annual TAAA repair volume was 1 to 2 (median, 1) for LVS and 3 to 18 (median, 7) for HVS. Overlapping ranges are due to variation from year-to-year absolute caseload volume. Seventy-two percent of HVS were also in HVH. Ninety-eight percent of HVS were found in either HVH or MVH.

Specific hospital level data, as defined by the NIS, were obtained from the database to further define hospital volume groups (Table I), and included teaching status, size according to number of beds, and geographic location. Teaching status was coded as teaching or nonteaching. Hospital size (number of beds) was defined as small, medium, or large. Geographic location was described as Northeast, Midwest, South, or West. HVH were more often large teaching hospitals, compared with MVH or LVH. No significant geographic variation was noted between volume groups.

Outcome variables. The primary outcome variable was in-hospital postoperative mortality. Secondary outcome measures were LOS and postoperative complications. LOS was adjusted to reflect postoperative hospital stay by subtracting hospital day number of the procedure from total LOS. Total burden of postoperative complications was tabulated with ICD-9-CM codes 996.0 to 999.0. Specific cardiac (997.1), pulmonary (997.3), urinary (997.5), and hemorrhagic (998.1, 998.11) complications, as well as renal failure (584.0, acute renal failure; 584.6, acute renal failure, cortical necrosis; 584.8, acute renal failure, not elsewhere classifiable; 584.9, acute renal failure, not otherwise specified; or 788.5, oliguria or annuria) were also analyzed.

Statistical analysis. Descriptive statistics for patient characteristics by provider volume were conducted. Univariate comparisons of provider volume, patient characteristics, calendar year, and outcome variables were performed with the χ^2 test, analysis of variance, Kruskal-Wallis test, and simple linear regression, where appropriate. Stepwise binary logistic regression (inclusion threshold, $P = .1$) of in-hospital mortality was used to test its association with provider volume after adjusting for potentially confounding patient case-mix variables and postoperative complica-

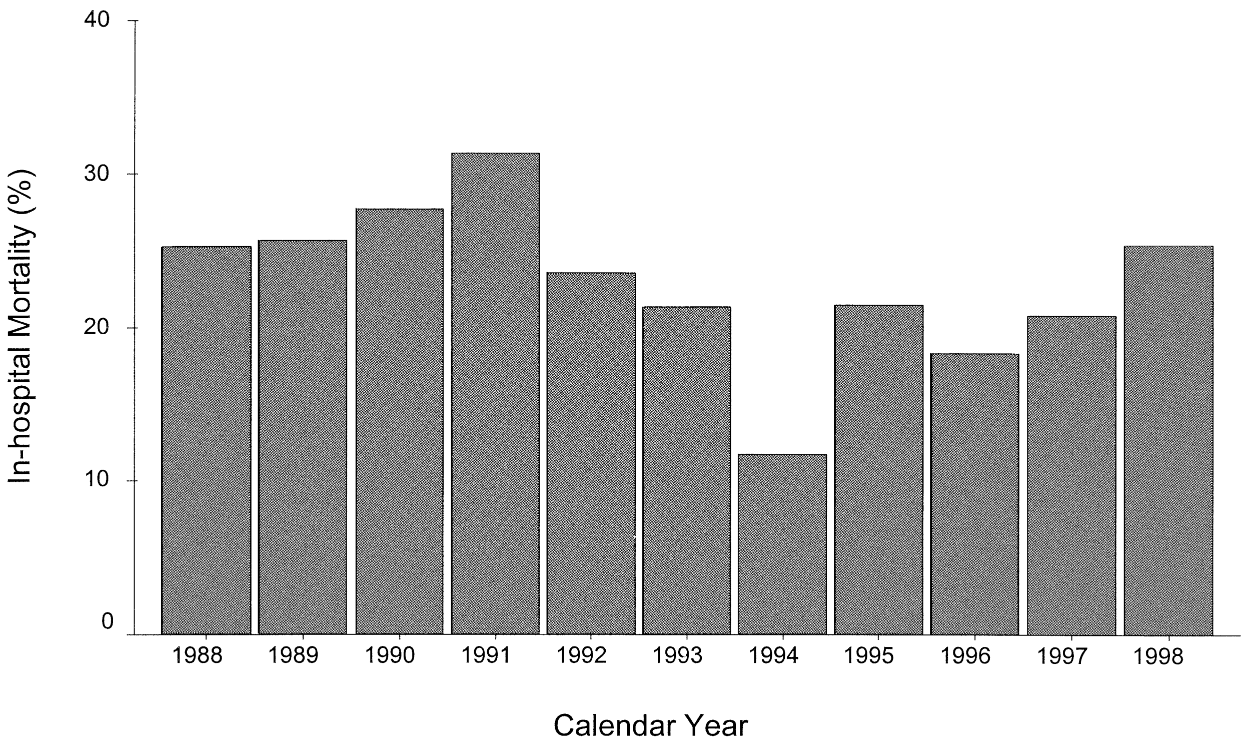

Fig 1. In-hospital mortality rate after TAAA surgical repair from 1988 to 1998 in the United States. Comparing 1988-1993 with 1994-1998, mortality rate improved 25.7% to 19.3% (P = .002).

tions. The multivariate model of mortality was tested for goodness of fit according to the Hosmer-Lemeshow method.[17] $P < .05$ was considered statistically significant in all final analyses. SPSS software (version 11.0; SPSS, Chicago, Ill) was used for all statistical analysis and graphing.

RESULTS

Overall mortality after TAAA repair was 22.3% in this series of 1542 patients. A significant improvement in mortality was observed from 1988 to 1998 (P = .002) (Fig 1). Mean (±SD) patient age was 68.4 (±9.7) years. Patient age was similar for hospitals with varying procedural volume (Table II). Men outnumbered women 59% to 41%. Most patients were white, and a higher rate of white patients received treatment at HVH. Most patients had at least one comorbid condition. Total comorbid disease burden was similar in the three hospital volume categories.

Mortality varied significantly for patients on the basis of hospital caseload volume (Fig 2). LVH had a 27.3% mortality rate, compared with 15.0% at HVH ($P < .001$) and 23.8% at MVH (P = .001) (Fig 2). Significant difference in mortality was also observed for surgeon volume (Fig 3). LVS had a 25.6% mortality rate, compared with 11.0% for HVS ($P < .001$). Subgroup analysis based on patient age revealed a significant variation in mortality by provider volume (Table III). Patients younger than 65 years experienced a 21.5% mortality rate at LVH, compared with 8.6% at HVH (P = .005). The difference in treating patients younger than 65 years was even greater between LVS and HVS: 21.0% and 3.4%, respectively ($P < .001$).

Median postoperative LOS was shorter for non-surviving patients compared with surviving patients (Table IV). Surviving patients at HVH had longer LOS (P = .004). Perioperative death rate within 24 hours of surgery was significantly different: 27.6% for HVH, compared with 30.6% for MVH and 42.3% for LVH (P = .041).

More than half of all patients had at least one postoperative complication after repair of an intact TAAA (Table V). On average, HVH had a higher rate of total postoperative complications compared with lower volume centers. HVH had a significantly higher rate of pulmonary complications compared with MVH or LVH (P = .033), and MVH had a higher rate of acute renal failure (P = .028). Other complications had similar rates of occurrence between hospitals with varying procedural volume.

Binary logistic regression models identified predictors of postoperative mortality (Table VI). Hospital volume and surgeon volume were entered in separate models. Significant risk factors for mortality included postoperative hemorrhage (odds ratio [OR] 4.4; 95% confidence interval [CI] 3.1-6.2; $P < .001$), acute renal failure (OR 3.5; 95% CI 2.4-5.0; $P < .001$), postoperative cardiac complications (OR 3.0; 95% CI 2.1-4.2; $P < .001$), LVS (OR 2.6; 95% CI 1.7-4.1; $P < .001$), LVH (OR 2.2; 95% CI 1.6-3.1; $P <$ .001), MVH (OR 1.7; 95% CI 1.2-2.4; P = .004), age 65 years or older (OR 1.6; 95% CI 1.2-2.2; P = .003),

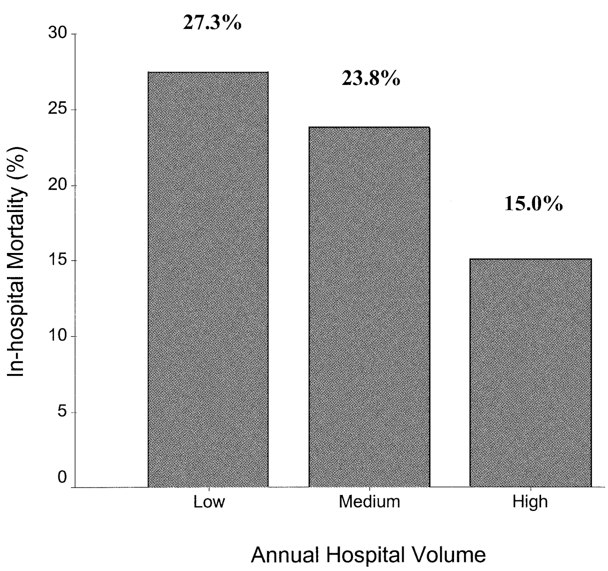

Fig 2. Variation in mortality by hospital volume after surgical repair of intact TAAAs. $P < .001$, Pearson χ^2 test.

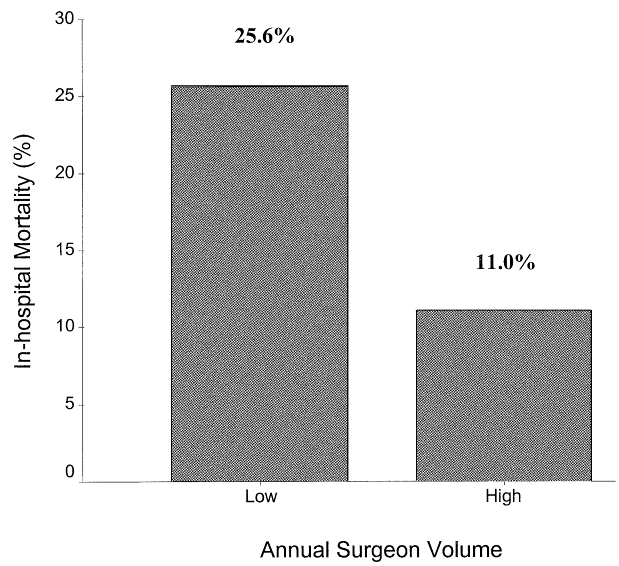

Fig 3. Variation in mortality by surgeon volume after repair of intact TAAAs. $P < .001$, Pearson χ^2 test.

Table II. Demographic data for patients who underwent repair of intact TAAAs in the United States from 1988 to 1998

	Annual hospital TAAA repair volume (median number of operations)				
	Total	*Low (1)*	*Medium (4)*	*High (12)*	P*
Patients (n)	1,542	569	467	506	—
Age (y), mean (SD)	68.4(9.7)	68.5(9.9)	68.3(9.9)	68.3(9.2)	.970†
Male gender (%)	59	60	58	58	.731
White race (%)	66	57	63	78	<.001
Comorbidity score‡ (%)					
0	2.7	4.2	1.7	2.0	.022
1	68.0	65.5	72.2	66.8	.060
2	26.1	27.3	23.3	27.3	.274
≥3	3.2	3.0	2.8	4.0	.597

Comparisons are made between hospitals with varying procedural volume.
TAAA, Thoracoabdominal aortic aneurysm.
*Pearson χ^2 test unless otherwise noted.
†Analysis of variance.
‡Scores represent total number of cardiovascular, pulmonary, hepatic, renal, and malignant conditions present.

nonwhite race (OR 1.5; 95% CI 1.1-1.9; $P = .009$), and emergent admission (OR 1.4; 95% CI 1.1-1.9; $P = .006$).

DISCUSSION

Provider caseload volume, as defined in this study, was a valid predictor of postoperative mortality after repair of intact TAAAs. The present investigation documented that patients with TAAAs treated at HVH and by HVS had a 42% and a 58% reduction in mortality, respectively. These data further suggest that patients younger than 65 years with intact TAAAs may benefit even more from referral to HVH and HVS. These differences persisted despite adjustment for patient demographic data, comorbid conditions, and inclusion of postoperative complications.

Median LOS for surviving patients increased minimally at HVH. This may reflect a more complicated postoperative course. Of importance, more than 40% of patients who died at LVH had LOS less than 24 hours. This was significantly different from that at higher volume hospitals and indicates that differences exist in perioperative management of these patients. Most patients had at least one postoperative complication after TAAA repair. Pulmonary, cardiac, and renal complications were most common at all hospitals.

Outcome for higher volume providers observed in this study is consistent with contemporary large single-institution reports. Coselli et al[3] reported a 4.8% mortality rate for TAAA repair. Increasing age, renal insufficiency, and symptomatic

Table III. Subgroup analysis of postoperative mortality based on patient age after intact TAAA repair in the United States from 1988 to 1998

	Annual hospital TAAA repair volume (median number of operations)					*Annual surgeon TAAA repair volume (median number of operations)*			
	Total	*Low (1)*	*Medium (4)*	*High (12)*	P*	*Total*	*Low (1)*	*High (7)*	P*
Patient age									
<65 y (%)	17.1 (75/438)	21.5 (37/172)	20.6 (26/126)	8.6 (12/140)	.005	14.9 (37/249)	21.0 (34/162)	3.4 (3/87)	<.001
≥65 y (%)	24.3 (268/1104)	30.0 (119/397)	24.9 (85/341)	17.5 (64/388)	<.001	21.7 (185/853)	27.7 (96/346)	13.6 (34/248)	<.001

Comparisons are made between hospitals and surgeons with varying procedural volume.
TAAA, Thoracoabdominal aortic aneurysm.
*Pearson χ^2 test.

Table IV. Postoperative LOS by hospital volume for patients who underwent surgical repair of intact TAAAs in the United States from 1988 to 1998

	Annual hospital TAAA repair volume (median number of operations)				
	Total	*Low (1)*	*Medium (4)*	*High (12)*	P*
Median LOS/(IQR) (d)†					
Surviving	12 (8-19)	11 (8-18)	13 (8-21)	12 (9-20)	.004
Not surviving	5 (1-16)	3 (0-14)	6 (1-17)	7 (1-18)	.101
LOS <24 hr (% total deaths)	35.3	42.3	30.6	27.6	.041

TAAA, Thoracoabdominal aortic aneurysm; *LOS*, length of stay; *IQR*, interquartile range.
*Kruskal-Wallis test, unless otherwise indicated.
†IQR (25th to 75th percentile) for LOS.
‡Pearson χ^2 test.

Table V. Postoperative complications by hospital volume for patients who underwent repair of intact TAAAs in the United States from 1988 to 1998

	Annual hospital TAAA repair volume (median number of operations)				
	Total	*Low (1)*	*Medium (4)*	*High (12)*	P*
Any complication (%)	55.2	51.5	56.8	57.9	.078
Cardiac (%)	14.8	12.8	13.9	17.8	.060
Pulmonary (%)	19.0	17.4	16.9	22.7	.033
Urinary tract (%)	9.9	7.7	10.5	11.7	.084
Hemorrhage (%)	12.4	14.8	11.8	10.3	.074
Acute renal failure (%)	14.2	12.3	17.8	13.0	.028

TAAA, Thoracoabdominal aortic aneurysm.
*Pearson χ^2 test.

enlargement were predictive of worse outcome in the former experience. This same group reported a 10% mortality for type II TAAA.[4] In 1509 patients undergoing TAAA operations, Svensson et al[5] reported an 8% postoperative mortality. Cambria et al[6] reported an 8.3% operative mortality in 337 consecutive patients undergoing TAAA repair from 1987 to 2001. Urgent or emergent operation was associated with increased risk for death, whereas age more than 70 years was not predictive of operative mortality. In a different patient sample, Rectenwald et al[7] reported a 10% postoperative mortality for elective repair and a 28% mortality for urgent TAAA repair. These latter authors observed at least one postoperative complication in most patients, a finding similar to that of the present study. Estrera et al[8] observed a 16% in-hospital postoperative mortality in their series of 654 patients. This group also found increased but acceptable mortality for patients 79 years or older.[18]

The reasons for a direct provider volume effect on outcome after TAAA repair are not well defined. Dimick et al[19] demonstrated that differences in rate of postoperative complications after AAA repair contributed significantly to volume-outcome effect. By reducing these complications, differences in mortality might be narrowed among providers with differing procedural volume. Data from the present

Table VI. Binary logistic regression model for postoperative mortality after TAAA repair

Risk factors	*Odds ratio*	*95% confidence interval*	P*
Emergent/urgent admission	1.4	1.1-1.9	.006
Age ≥65 (y)	1.6	1.2-2.2	.003
Female gender	.87	0.67-1.1	.318
Nonwhite race	1.5	1.1-1.9	.009
Comorbidity score†			
1	0.90	0.40-2.0	.796
2	0.89	0.38-2.0	.774
≥3	2.1	0.77-5.9	.147
Postoperative complication			
Cardiac	3.0	2.1-4.2	<.001
Pulmonary	0.48	0.33-0.71	<.001
Urinary	1.2	.77-1.9	.443
Hemorrhage	4.4	3.1-6.2	<.001
Acute renal failure	3.5	2.4-5.0	<.001
Hospital volume			
Low (median, 1 case)	2.2	1.6-3.1	<.001
Medium (median, 4 cases)	1.7	1.2-2.4	.004
Low surgeon volume‡ (median, 1 case)	2.6	1.7-4.1	<.001

TAAA, Thoracoabdominal aortic aneurysm.
*Hosmer-Lemeshow test, X = 4.8, $P = .777$.
†Reference group is a comorbidity score = 0.
‡Surgeon volume and hospital volume variables were run in separate regression models.

study suggest that postoperative complications contribute to mortality but do not completely explain observed differences in outcome. For example, when complications are included in the regression model, volume variables do not lose significance. The high rate of death within the first 24 hours experienced with lower volume providers suggests that important operative and immediate postoperative hazards may occur in their patients. This may provide more impetus to refer patients to centers with the latest in surgical techniques, monitoring, and anesthesia, and a multidisciplinary approach to postoperative management.

The present study has certain limitations. First, the nature of administrative data precludes determination of certain variables, eg, aneurysm type, blood loss, hemodynamic status, cross-clamp time, spinal drainage, and aortic distal perfusion, which may influence outcome. Second, determination of mortality was made during an index postoperative hospitalization. Therefore difference in long-term mortality between various providers is unknown. Finally, determination of postoperative complications and comorbid conditions relies on secondary diagnostic codes, which may not be recorded with 100% accuracy or contain information regarding severity. This may explain, for example, the inability of certain postoperative complications or comorbid conditions to predict mortality in this population. There is no evidence, however, that provider volume affects coding of these variables. Thus relative differences between groups should be accurate.

Despite incremental improvement in outcome after intact TAAA repair from 1988 to 1998, overall mortality in the United States continues to be higher than that commonly published in selected single institutional series. The relative infrequency of TAAA and the fact that most are intact at presentation, coupled with large variation in outcome between providers with different caseload volume, suggests that regionalization of these complex surgical procedures may be practical and in the patient's best interest.

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